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Title:	Use of Computer Vision for Analysis of Image Data Sets from High Temperature Plasma Experiments
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Use of Computer Vision for Analysis of Image Data Sets from High Temperature Plasma Experiments

P. M. Kozlowski, Y. H. Kim, B. M. Haines, T. Day, T. J. Murphy, H. F. Robey, H. M. Johns, T. S. Perry

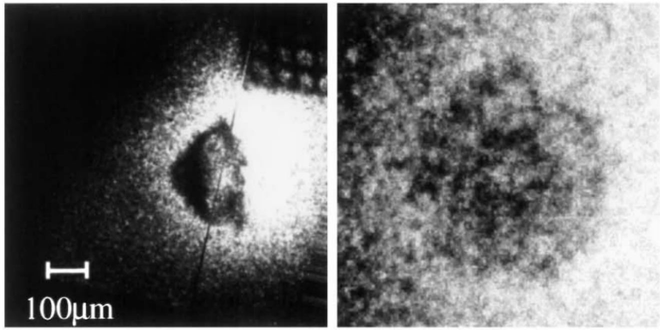
Physics Cafe

P-Div, LANL

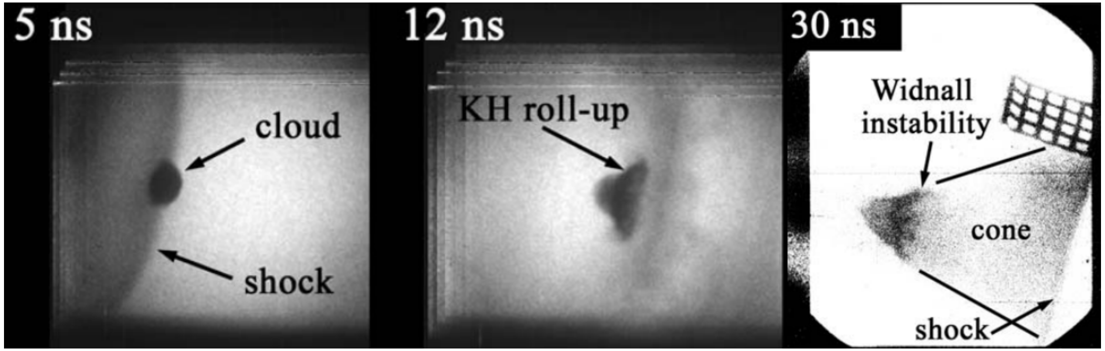
2021-03-04

LA-UR-

Radiography is ubiquitous in HED, but analysis is typically limited to 1D lineouts



Side and face-on SBI radiographs on Omega. Lineouts used for mode analysis. [2]



ISM mass stripping experiment on Omega. Observed Widnall instability. Lineout study of normalized width/height [1].

[1] J. F. Hansen et al. PoP 14, 056505 (2007). DOI: 10.1063/1.2714024
[2] H. F. Robey et al. PRL 89, 8 (2002). DOI: 10.1103/PhysRevLett.89.085001

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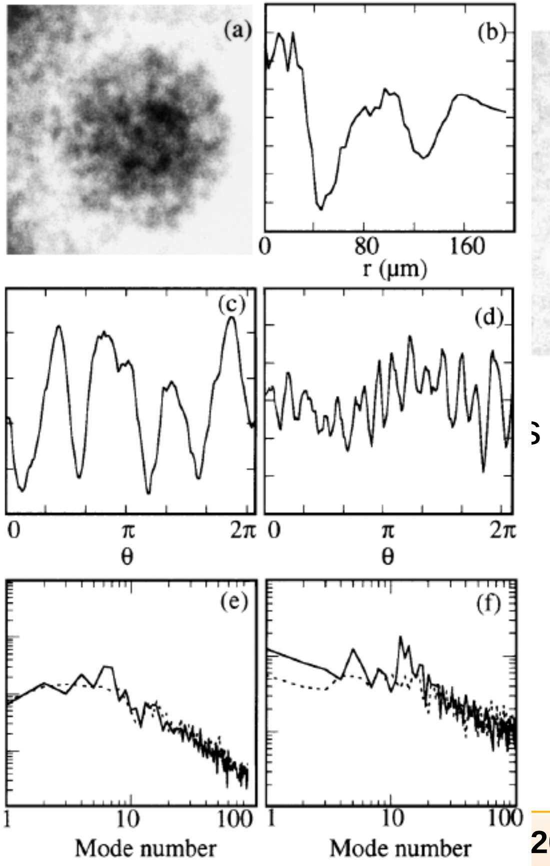
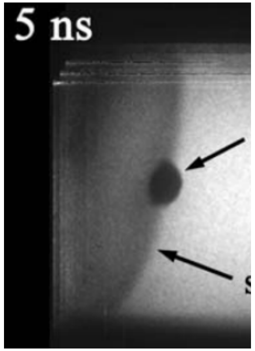
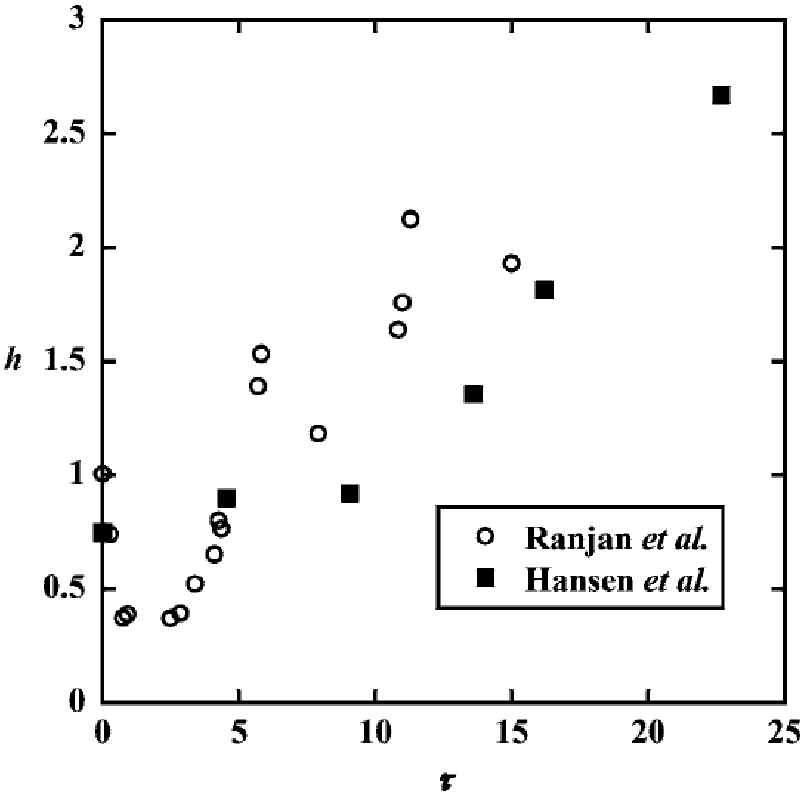
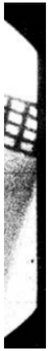


Side
on C
mod



ISM mas
Observec
normalize



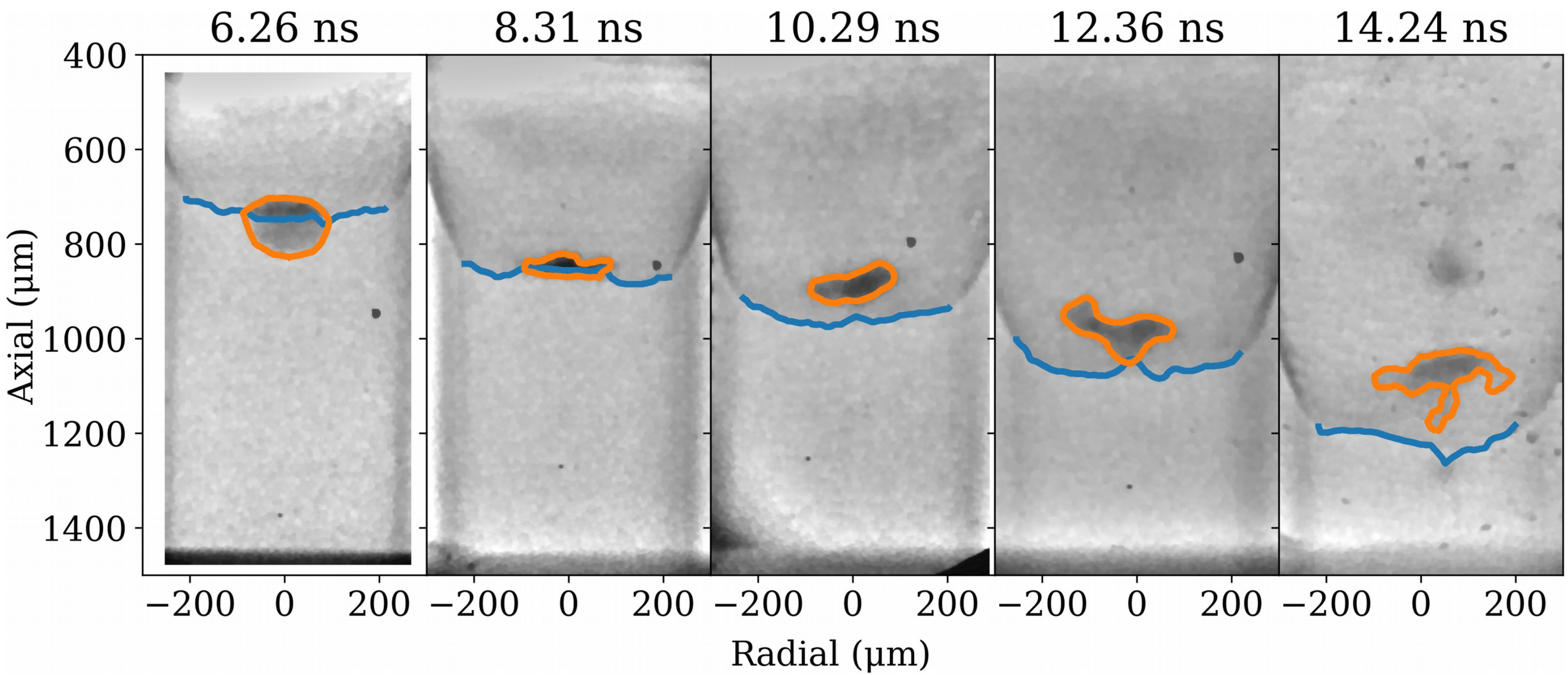


[1] 2007). DOI: 10.1063/1.2714024
[2] H. F. Robey et al. PRL 89, 8 (2002). DOI: 10.1103/PhysRevLett.89.085001

Using computer vision we can track full 2D interactions over time.

Blue = shock contour
Orange = void contour

Marble VC 16A
Each image = different shot



Computer Vision Techniques

Why computer vision?
Semi-automated analysis on small datasets.

Human Vision

- Feature ID
- Robust

- Biased
- Qualitative

Computer Vision

- 2D
- Reproducible
- Single images

- Feature engineering
- uncertainty

Pros Cons

Lineouts/ Histograms

- Quick
- Simple

- Brittle
- Noise issues
- 1D

Machine Learning

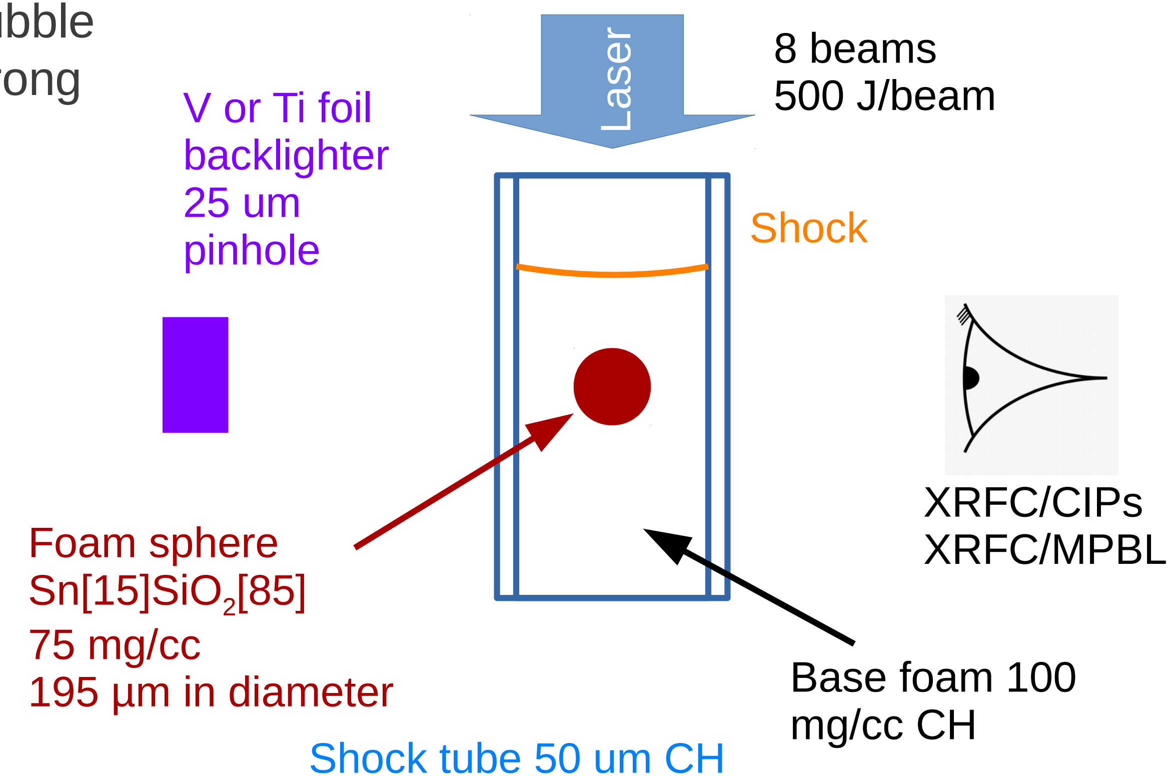
- 2D
- Feature ID

- Training
- Large datasets

Example radiographs from Marble VC, a platform for testing our understanding of SBI in plasmas

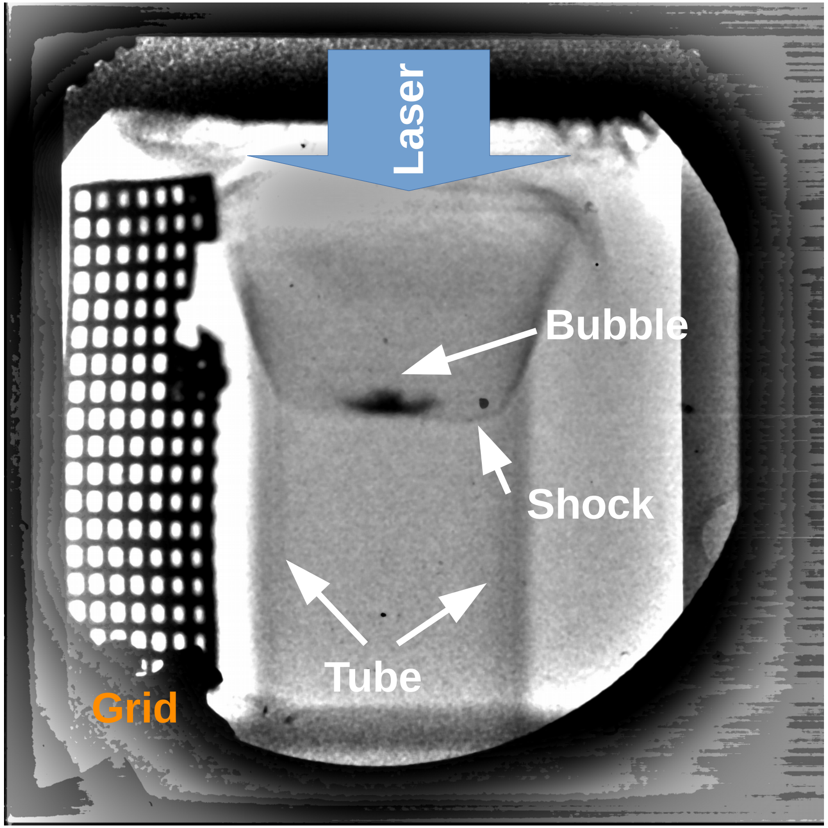
- Complex physics of shock-bubble interaction (SBI) provide a strong test for theory/simulations
  - Compression
  - Morphology/mix
  - Instabilities

- Optimized for contrast
- Bubble is lower density than ambient (**divergent SBI**), but higher attenuation due to dopant

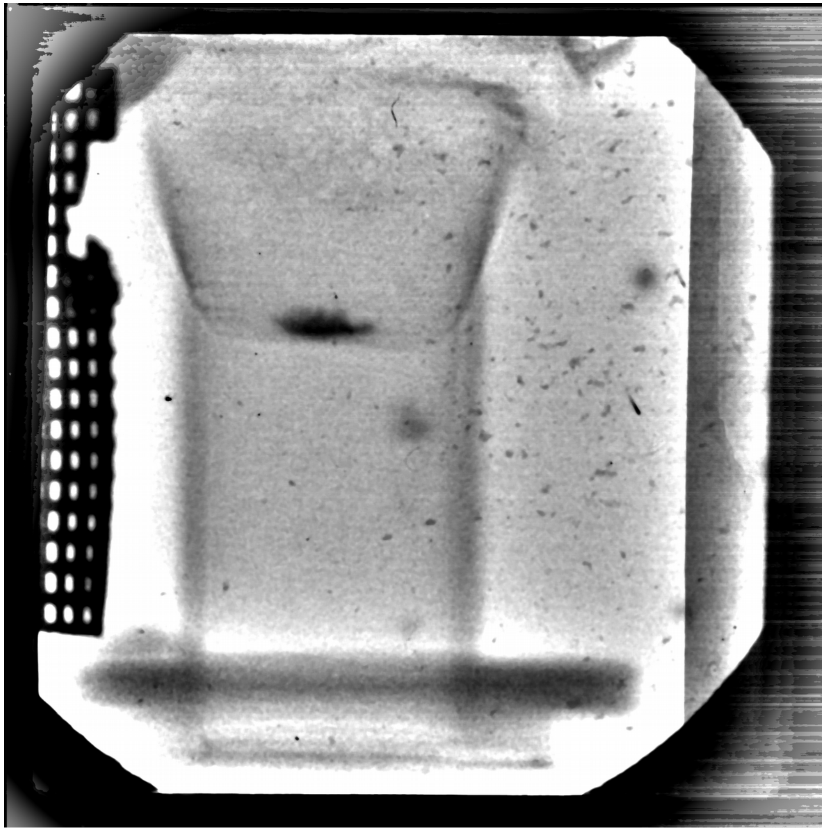


The Marble VC campaign was supported by the Office of Experimental Science Primary Assessment Technologies and Secondary Assessment Technologies Programs

Marble VC platform produces radiographs of SBI along two orthogonal lines of sight

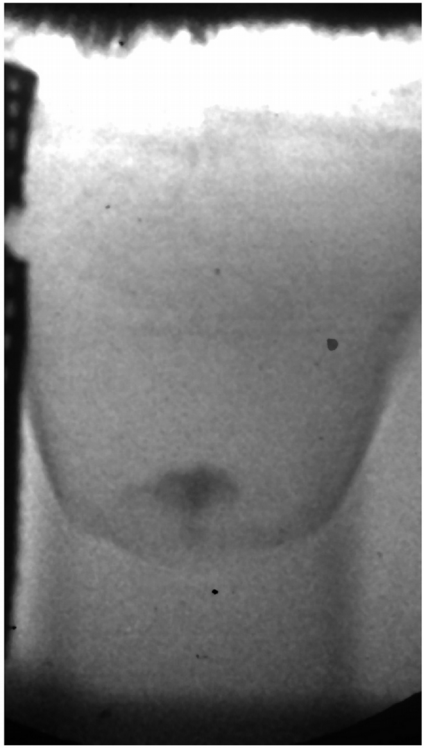


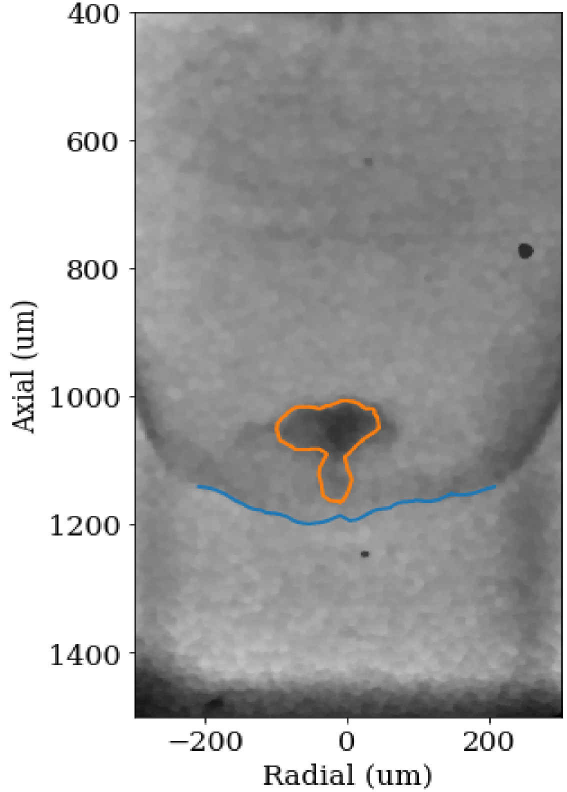
TIM 6, XRFC 3, MPBL, V BL



TIM 3, XRFC 5, CIPs, Ti BL

Using computer vision libraries we extract shock and bubble contours from raw radiographs

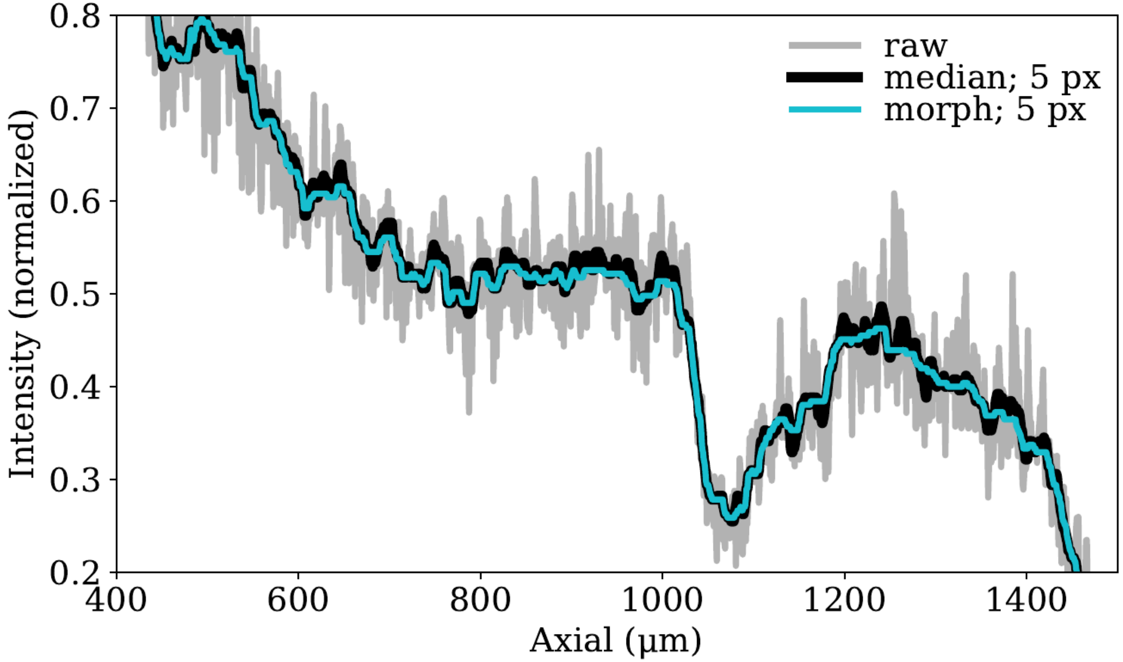




- Computer vision techniques:
  - Morphological filtering cleans hot pixels and camera artifacts
  - Watershed segmentation retrieves contours
  - Reduce bias from human input
  - Increase reproducibility

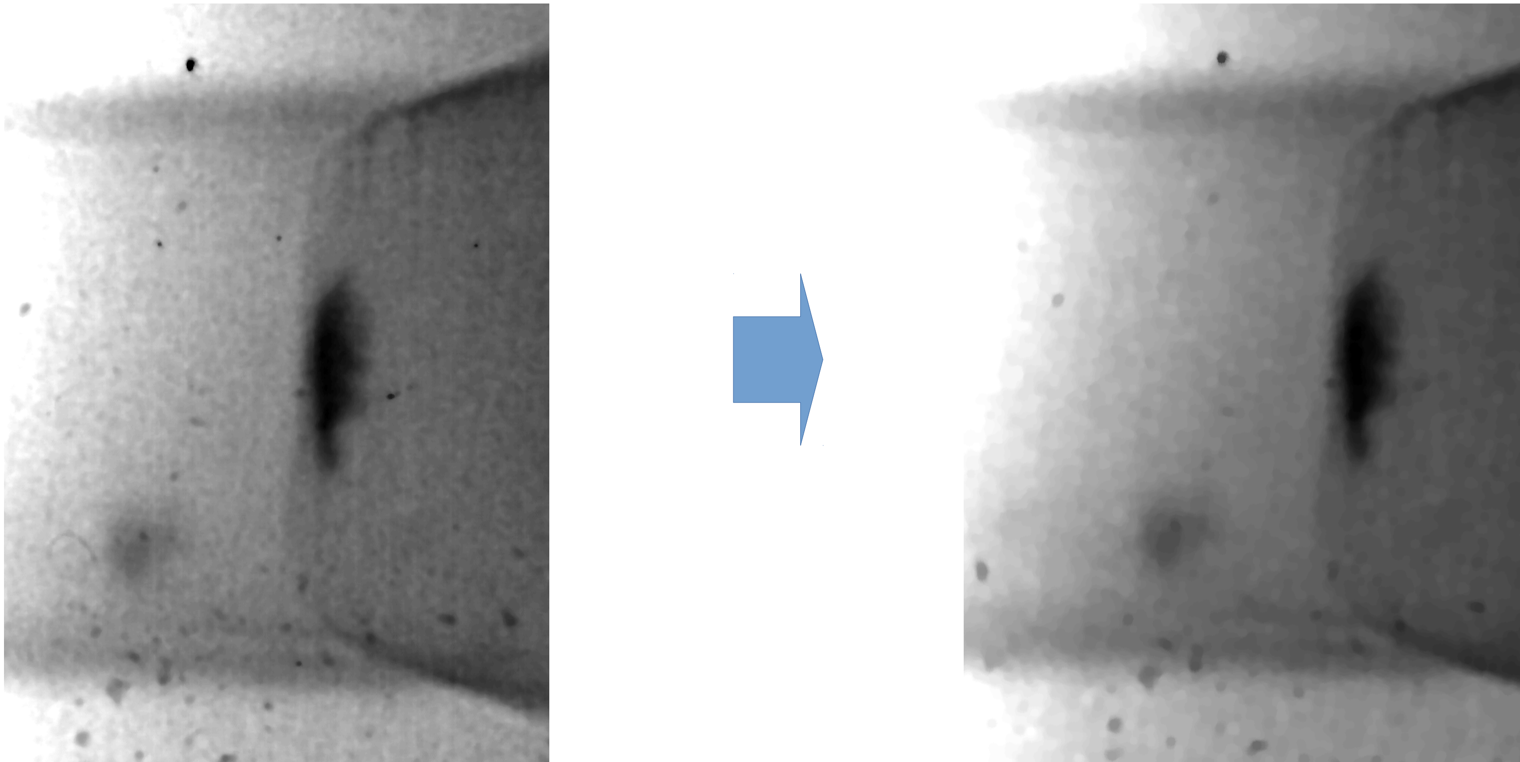
“Use of computer vision for analysis of image datasets from high temperature plasma experiments” accepted to RSI proceedings of the 23rd HTPD conference

Median and morphological filters remove noise while preserving edges

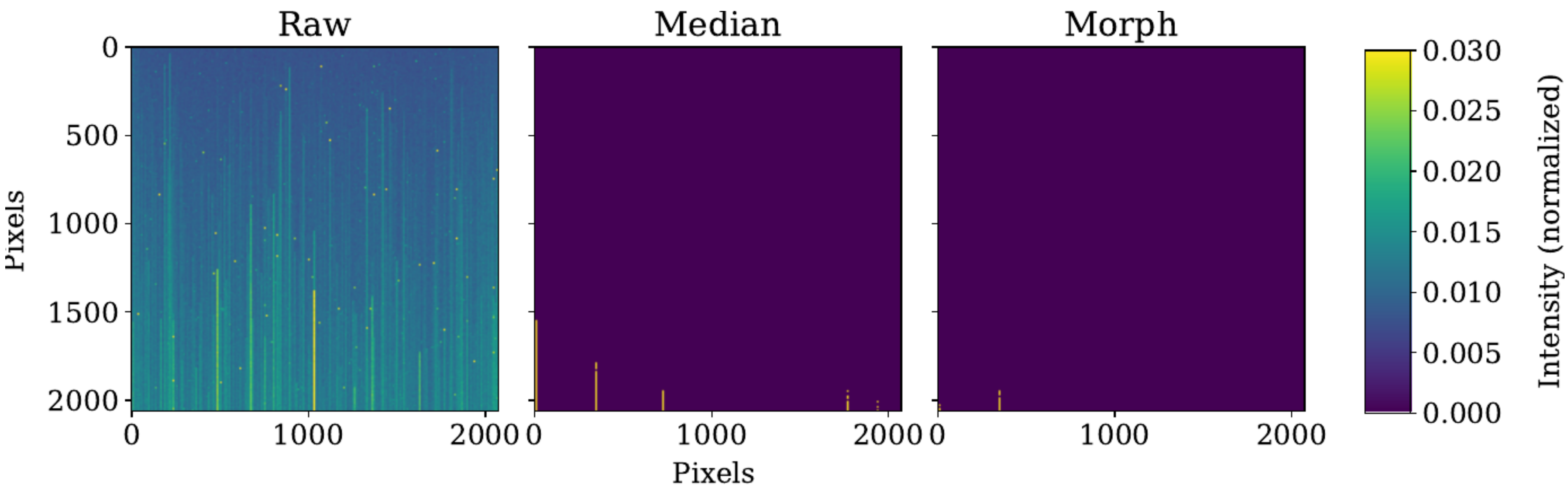


- Median filters remove impulse noise
- Morphological filters remove “salt and pepper” noise and small cracks
- Disk kernel of radius 5 pixels was found to be suitable for this image set
- General trend of dip in intensity at shock/bubble does not seem distorted

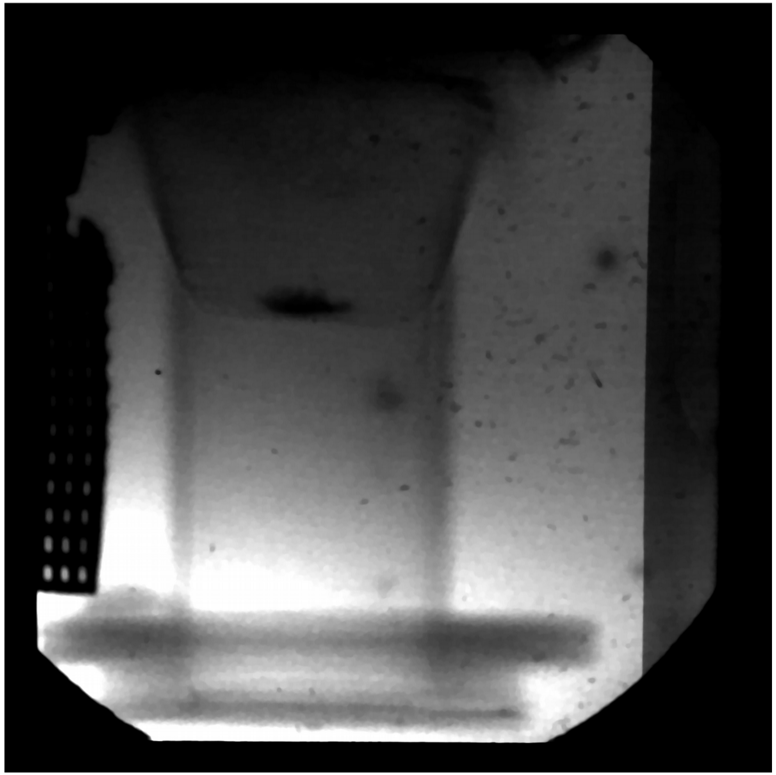
Morphological filters remove small artifacts

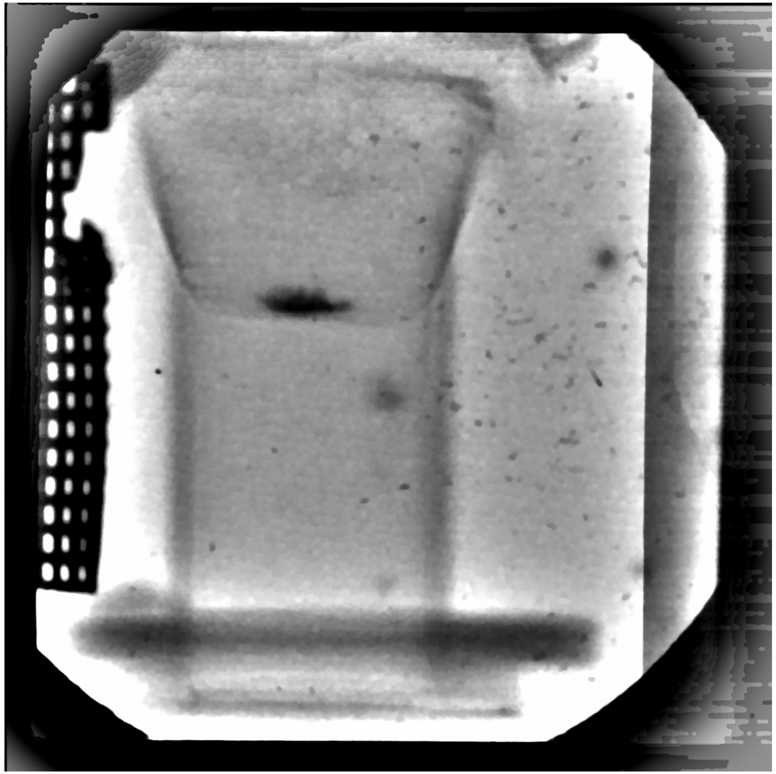


Median/morphological filtering also cleans hot pixels and “streaks” inherent to using x-ray framing cameras



Pseudo-flatfielding removes large lighting variations and preserves short scale contrast gradients

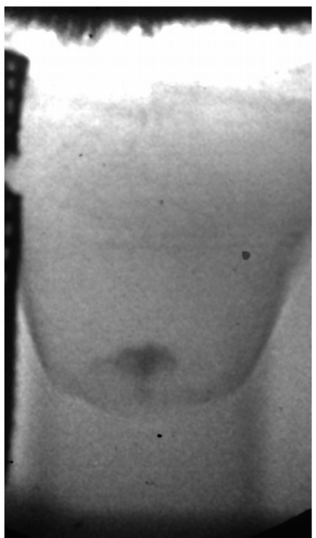




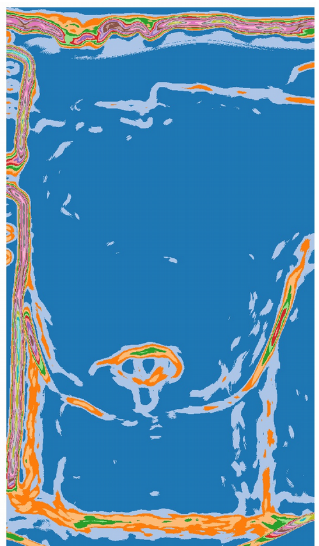
Watershed segments the image based on topological features

Watershed segmentation uses 2D info, and is less susceptible to noise/gaps at feature edges

Input

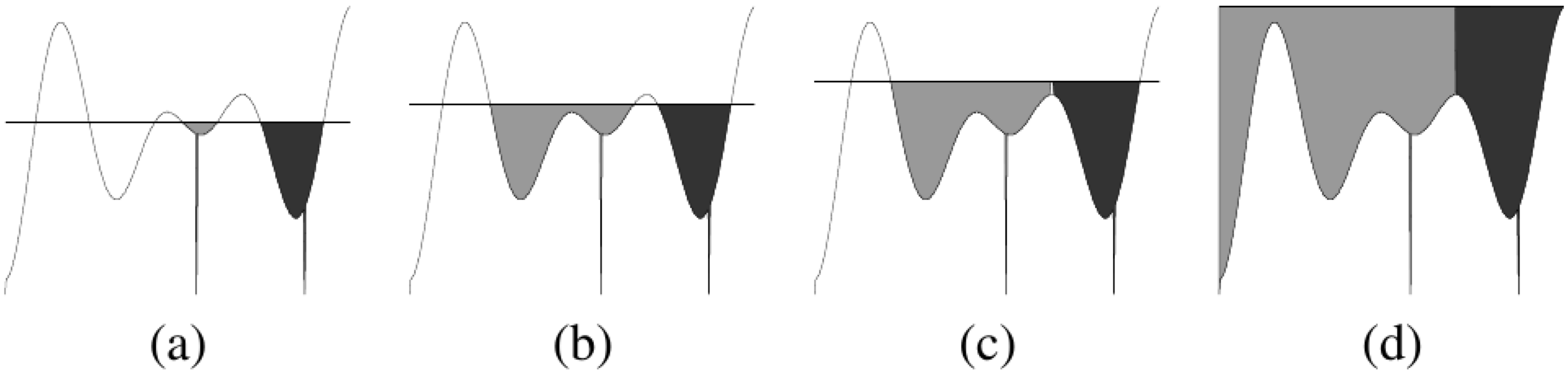


Gradients



Markers

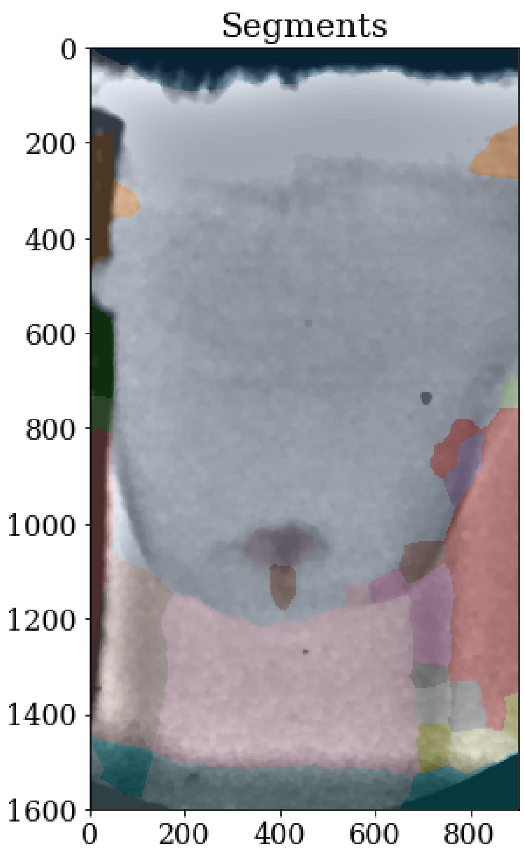
Watershed segmentation divides the image like a topological map

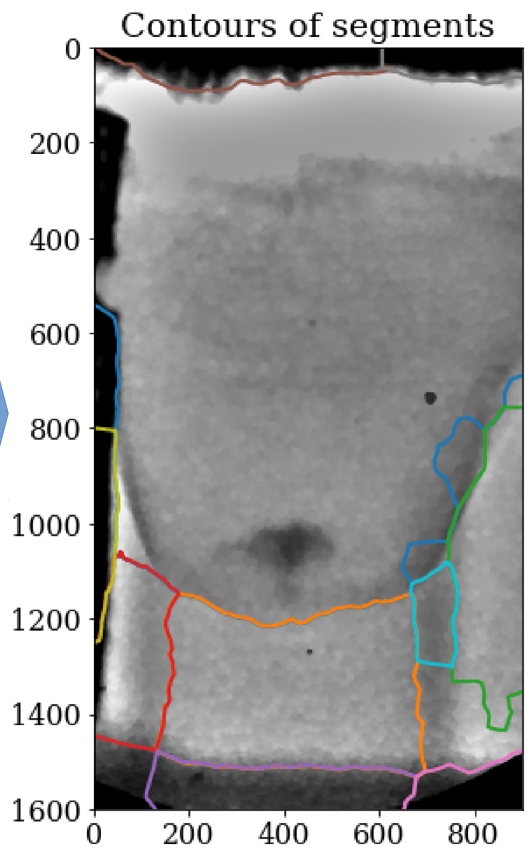


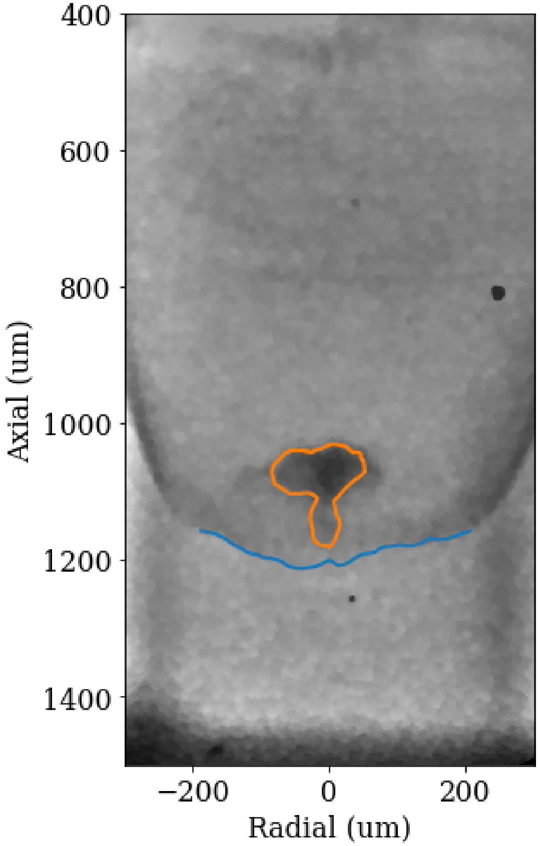
- Initiate markers of different regions
- Fill regions, starting from minima, with different colors of water
- Where different colors meet, build a “dam” marking the boundary between segments
- Keep filling with water until all peaks are under water

[1] E. R. Dougherty. Hands On Morphological Image Processing. SPIE Press (2003).

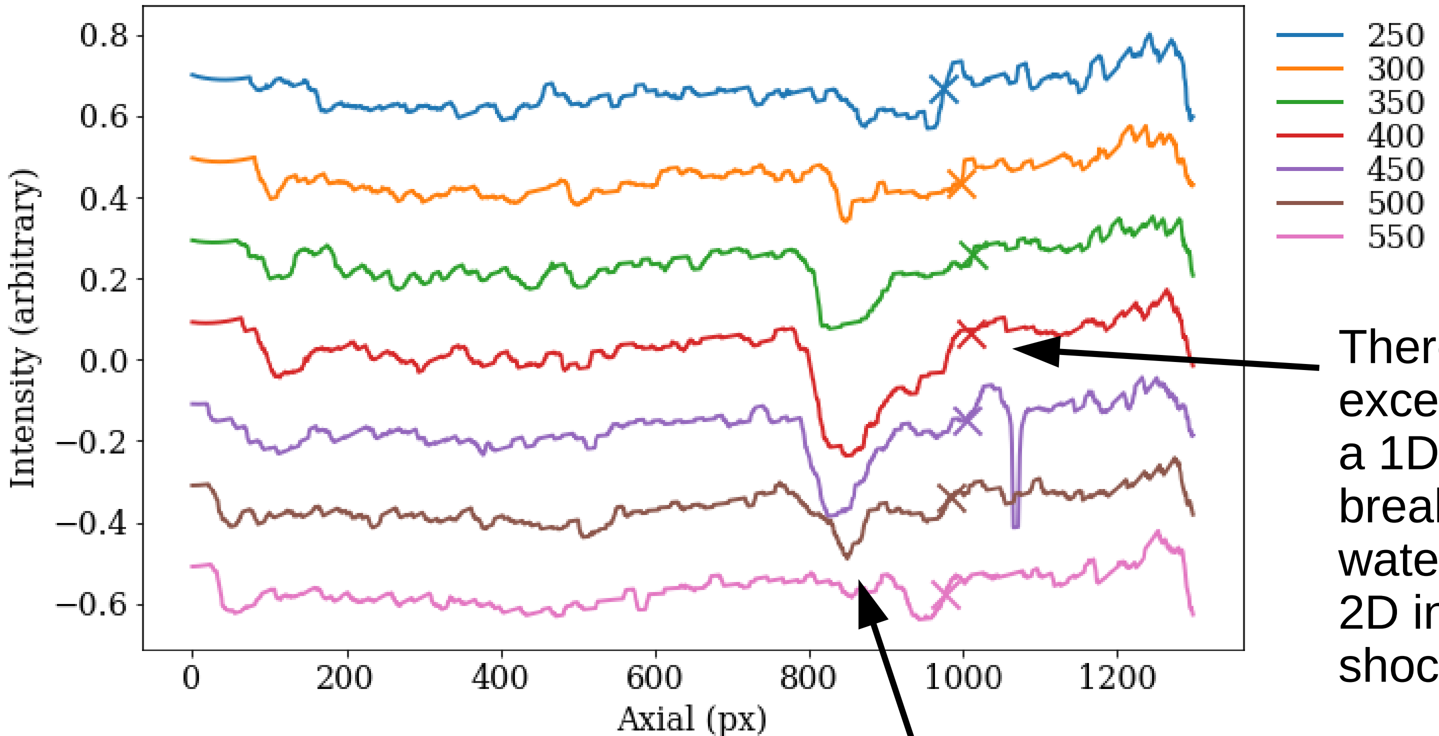
Contours are taken around segment and then indexed to relevant portions







Ridge plots show shock position is identified in middle of contrast gradient, when a clear gradient exists



There are some exceptions where a 1D lineout would breakdown, but watershed uses 2D info to still find shock position

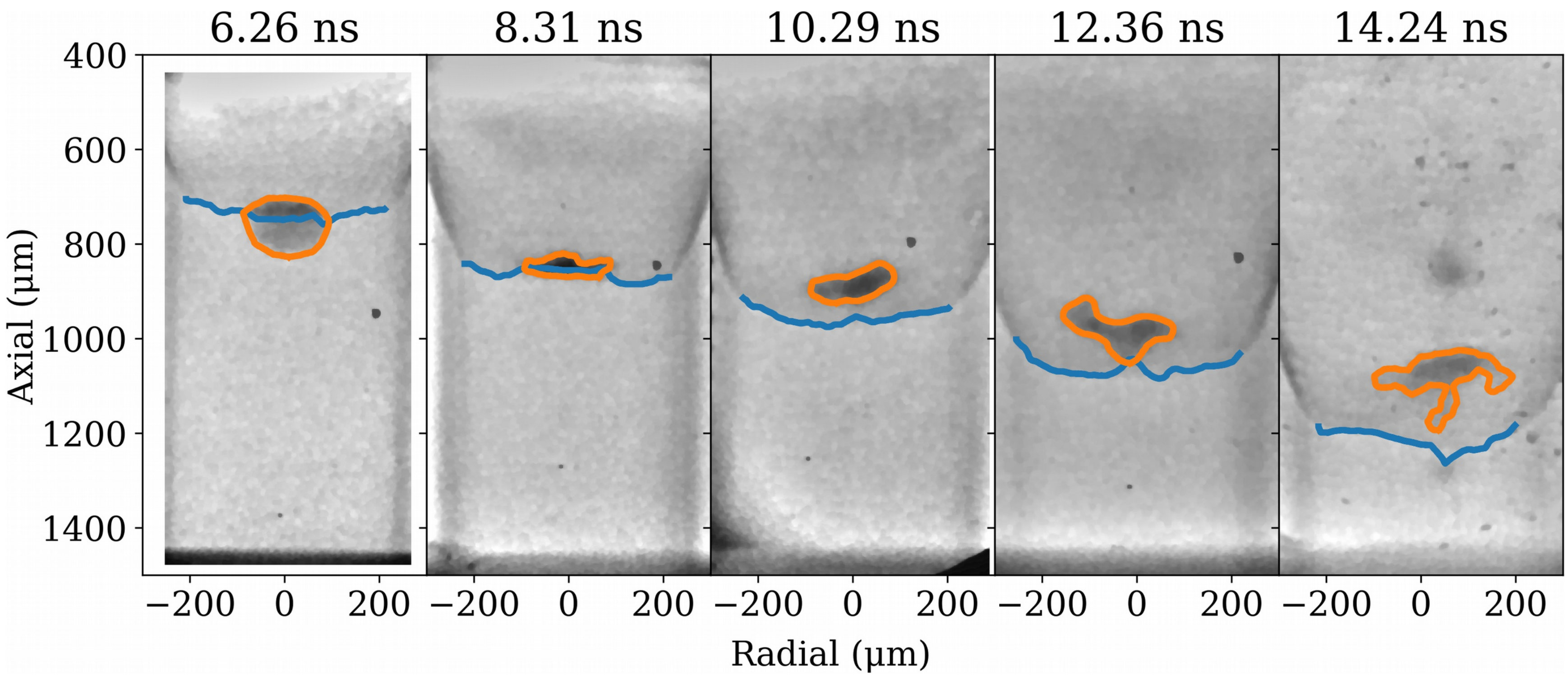
Bubble

Experiments and Simulations

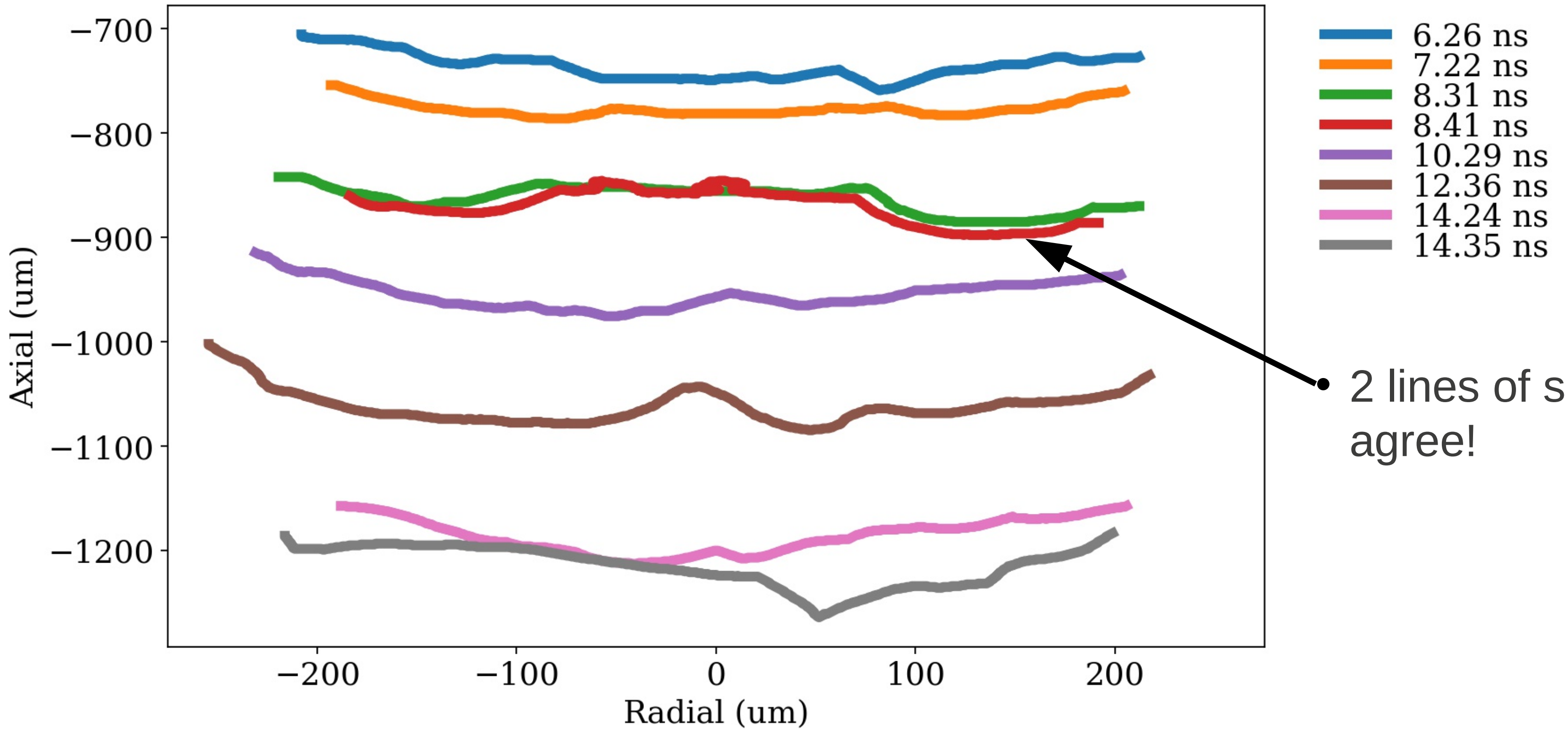
Using computer vision on Marble VC data we can track the full 2D interaction over time.

Blue = shock contour
Orange = void contour

Each image = different shot

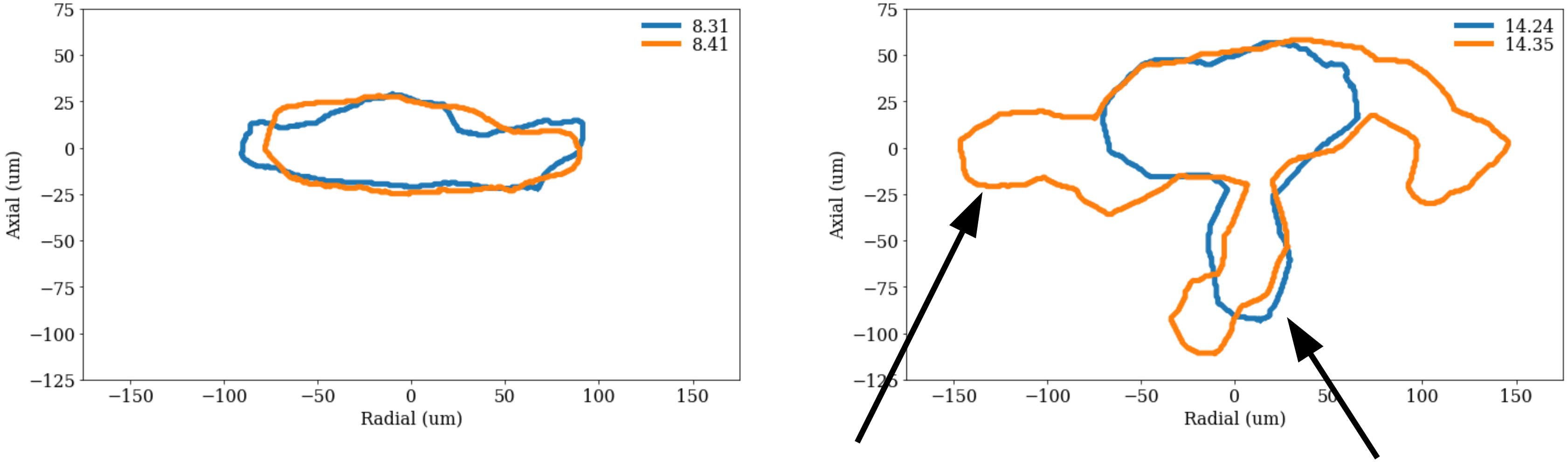


We can now diagnose symmetry between two lines of sight on the same shot



- 2 lines of sight agree!

We can quantitatively track the distortions in the bubble over time and from different views

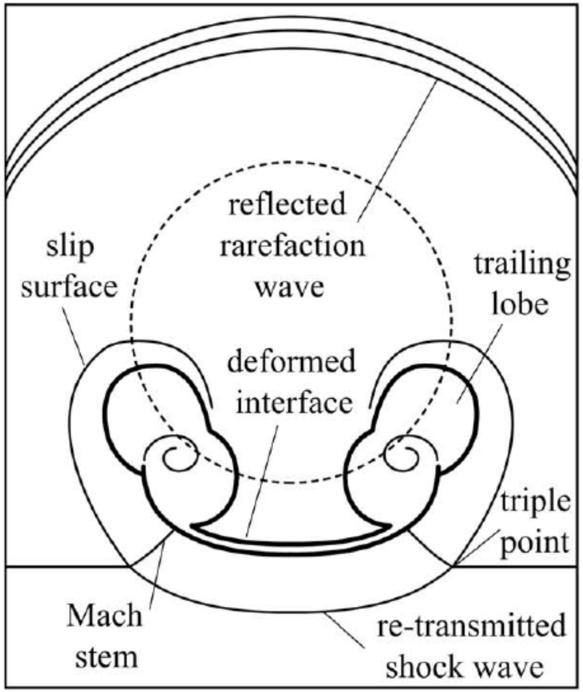


Vorticity deposition

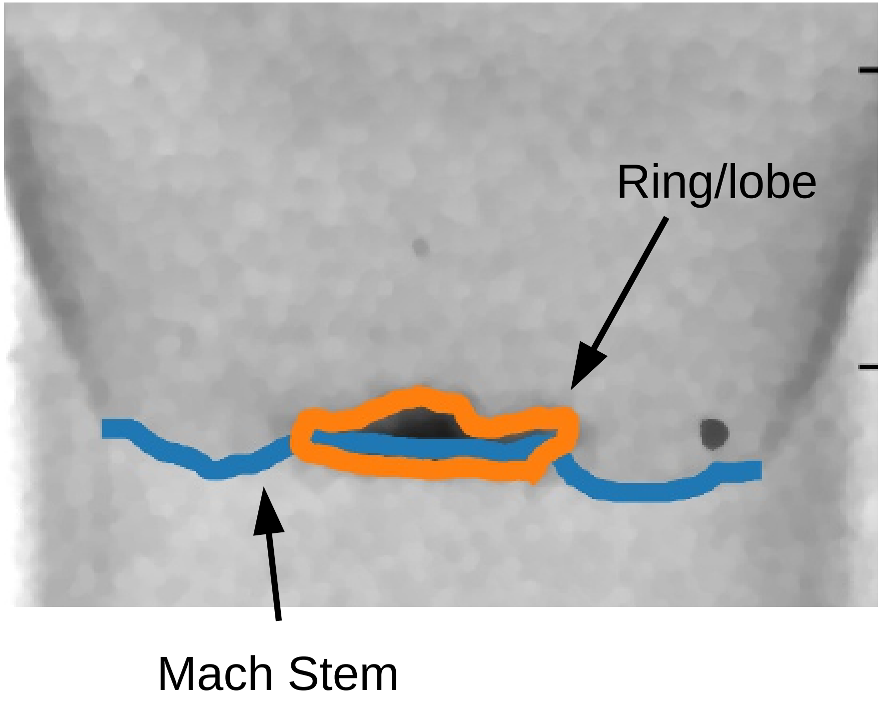
Shock focusing? Jetting Sn?

Simultaneous images of bubbles from two lines of sight enable us to check for cylindrical symmetry in the system

We begin to examine divergent SBI in detail, closing the gap between classical hydro and HED data

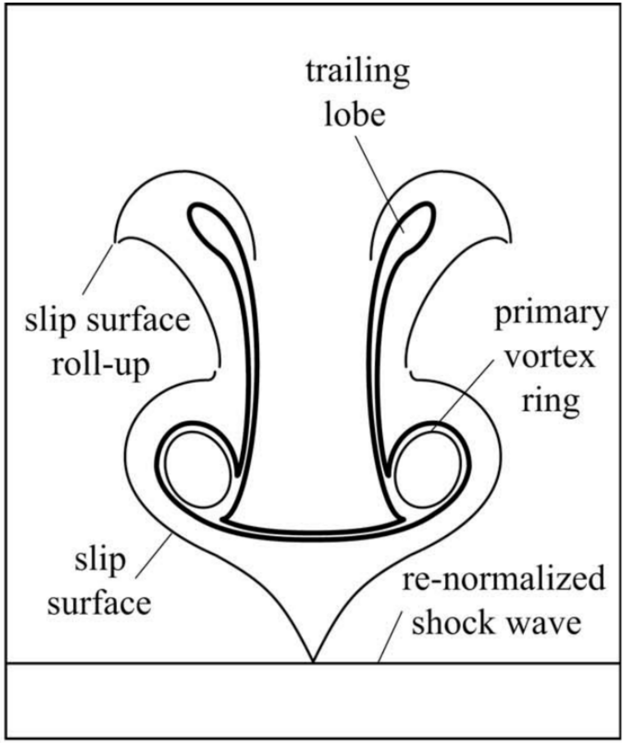


8.31 ns, 81429, XRFC 3

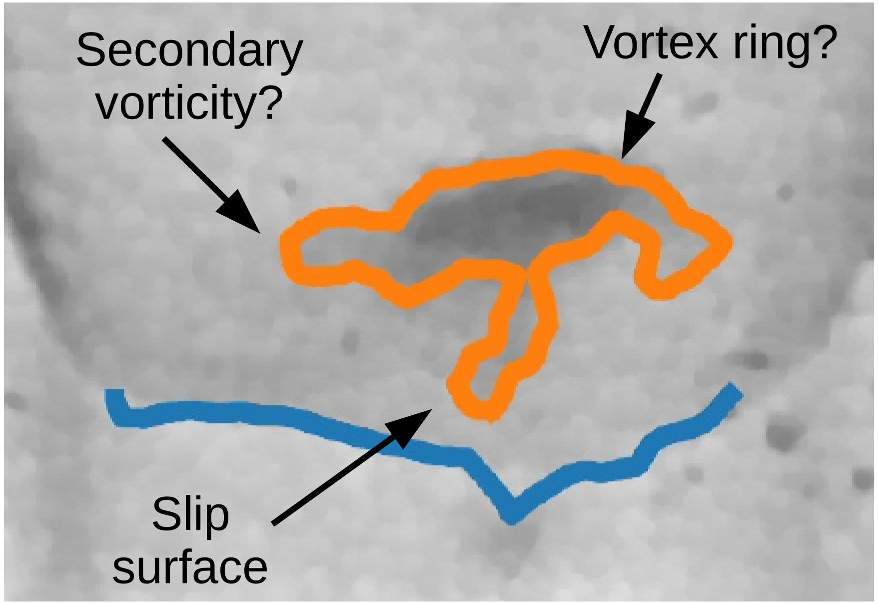


D. Ranjan et al. Phys Fluids. 20, 036101 (2008). doi.org/10.1063/1.2840198

Later time images are not as clear and require further interpretation

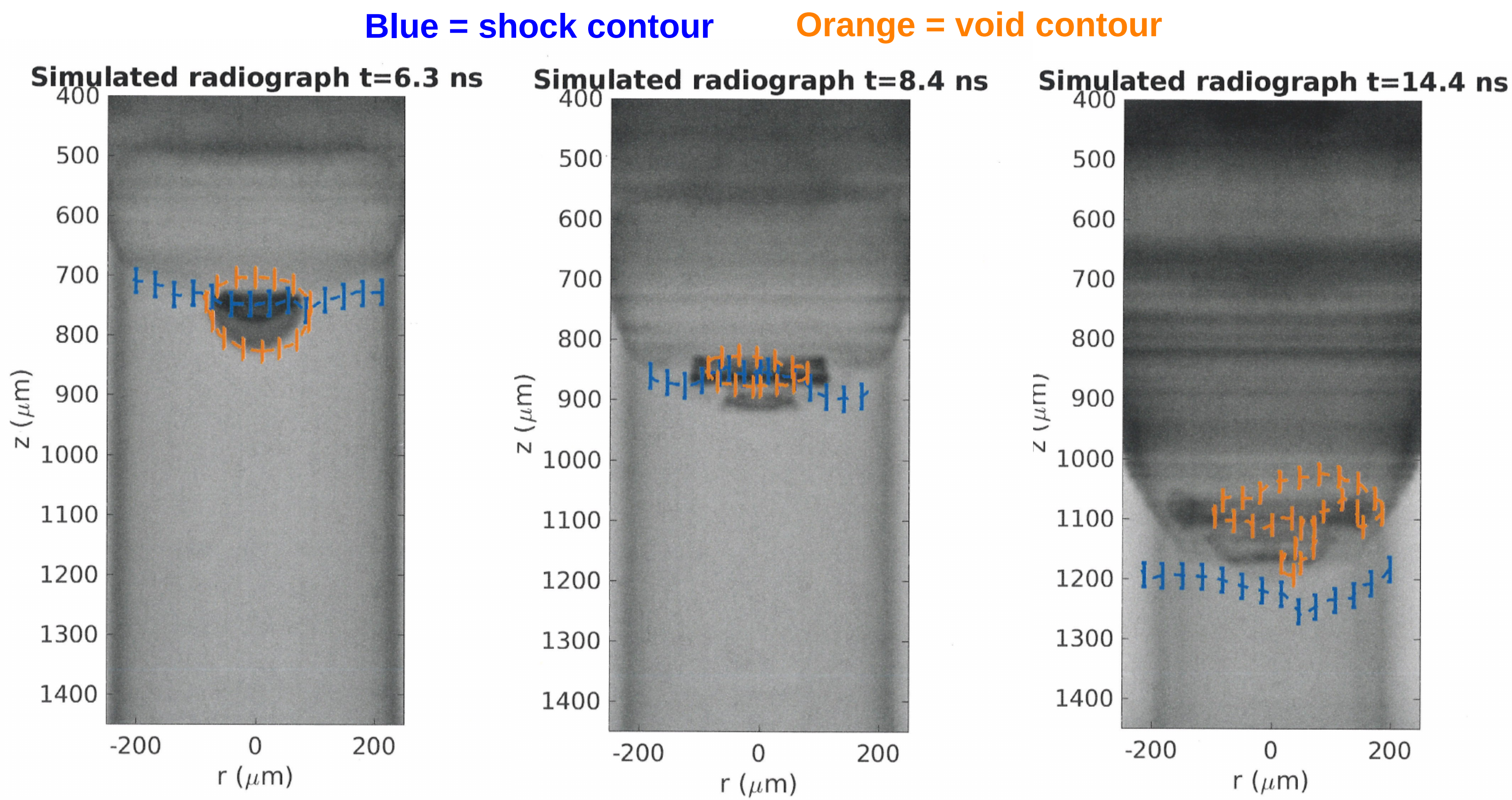


14.24 ns, 81431, XRFC 3



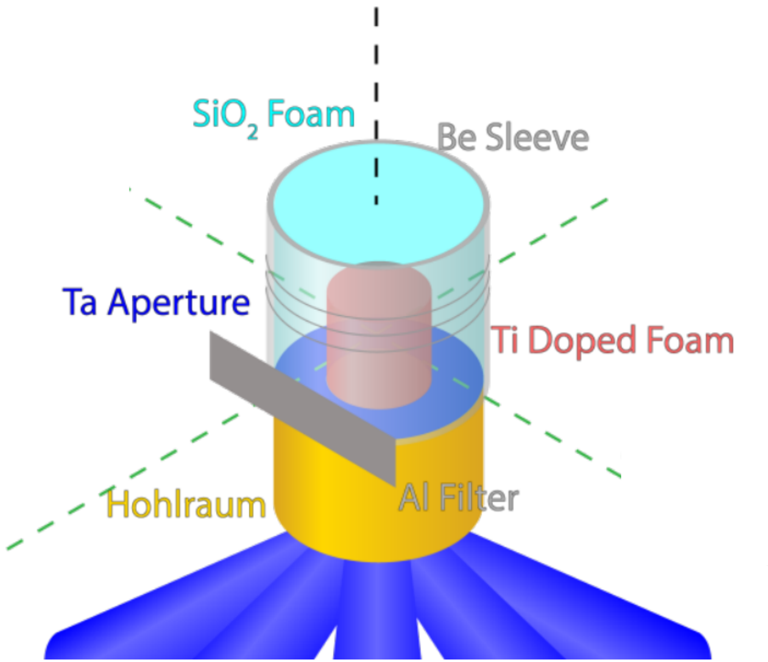
D. Ranjan et al. Phys Fluids. 20, 036101 (2008). doi.org/10.1063/1.2840198

Direct comparisons between xRAGE simulations and experiments show early time agreement and late time discrepancies

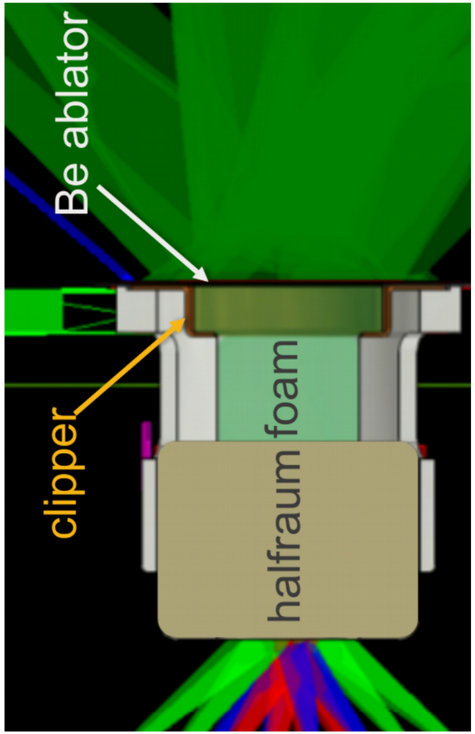


- Simulations produced by B. M. Haines

XRIPL is general enough to work on radiographs from other campaigns (COAX, Radishock)



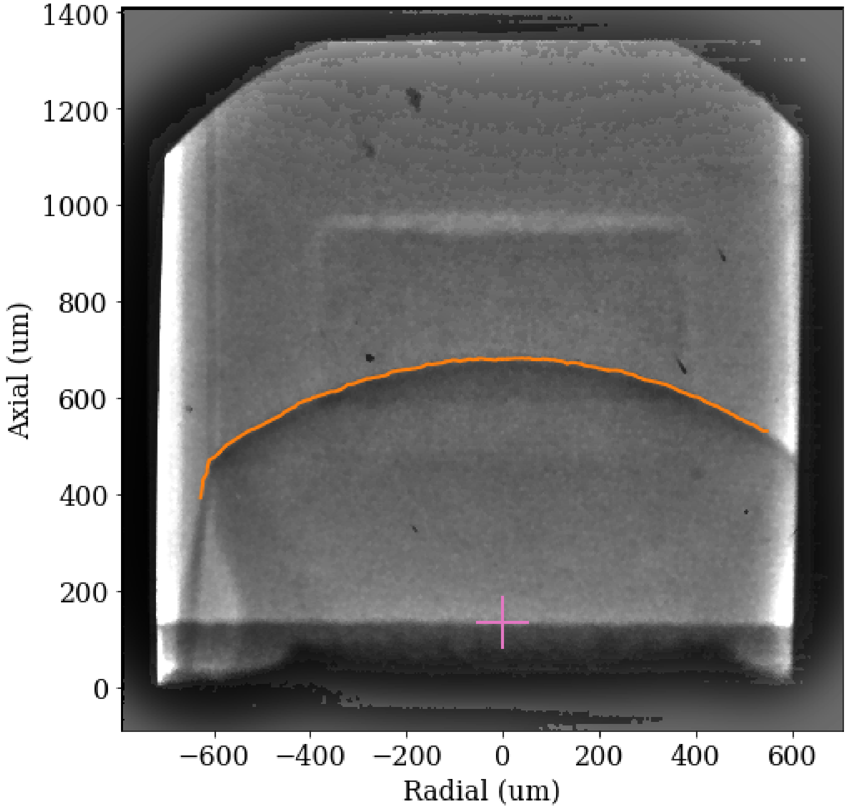
COAX: Radiation flow across a boundary



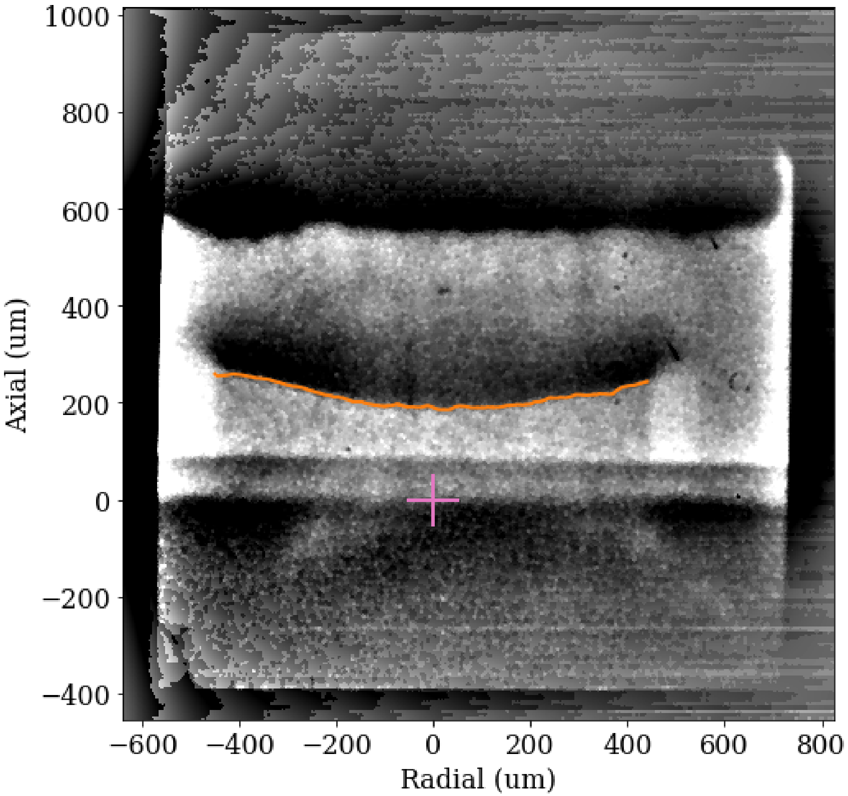
Radishock: Radiation flow meets an opposing shock

XRIPL is general enough to work on radiographs from other campaigns (COAX, Radishock)

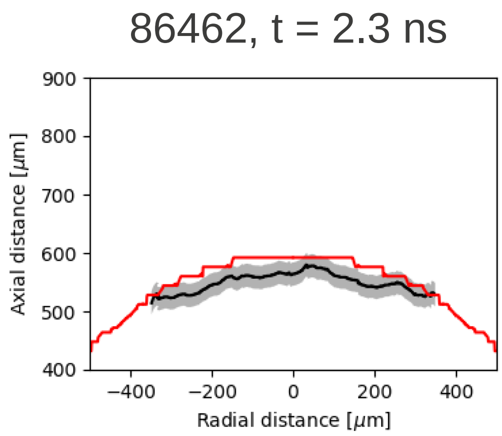
COAX 86456

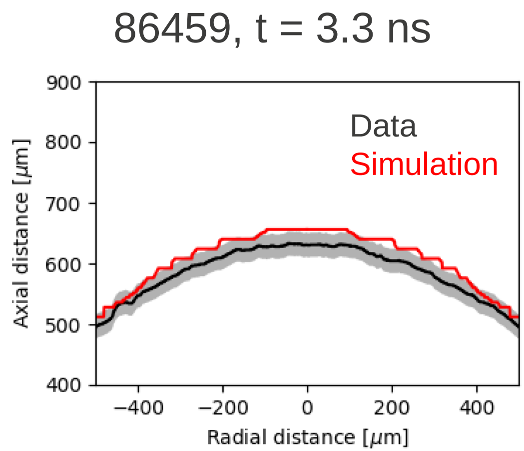


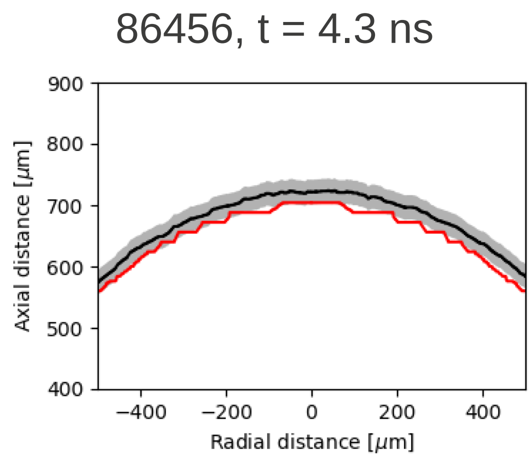
Radishock 94789



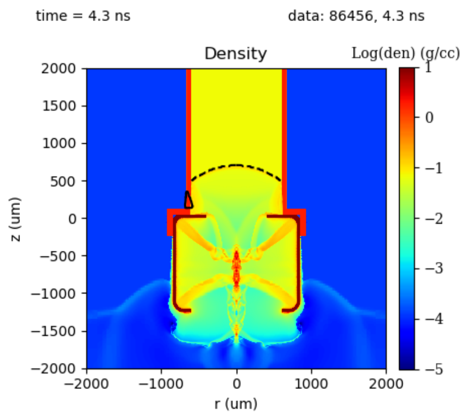
Direct comparisons of shock curvature for COAX experiments and simulations show agreement





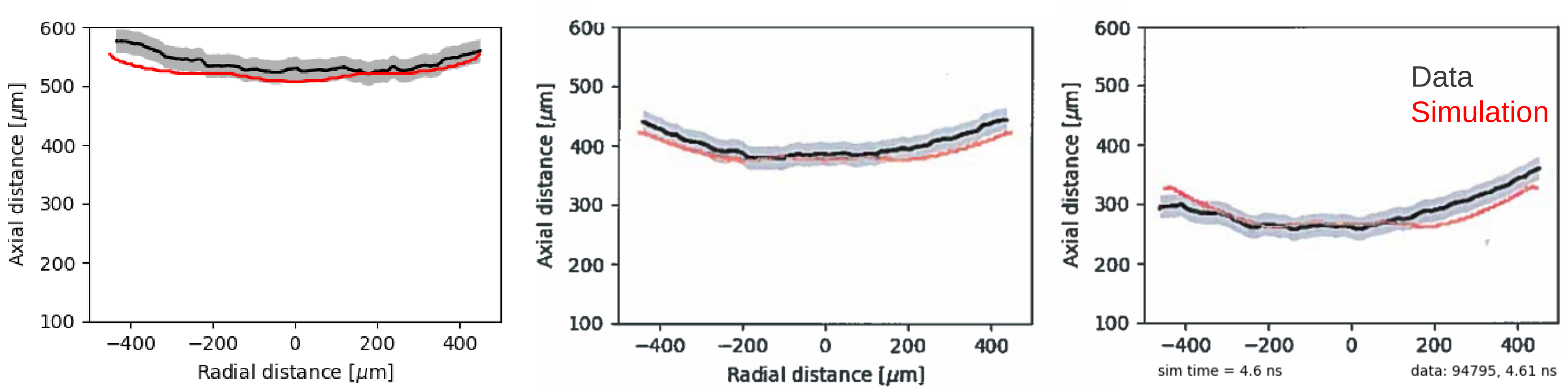


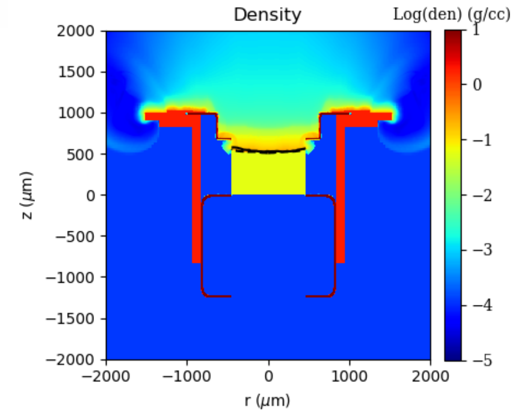
- Cassio simulations were generated by H. F. Robey.
- Inline CBET for indirect drive experiment
- 0.6x laser drive multiplier
- Flux limiter 0.05
- Can quantitatively interrogate fine scale differences



Direct comparisons of shock curvature for Radishock experiments and simulations show agreement

94795, t = 4.6 ns   96981, t = 6.6 ns   96990, t = 8.2 ns

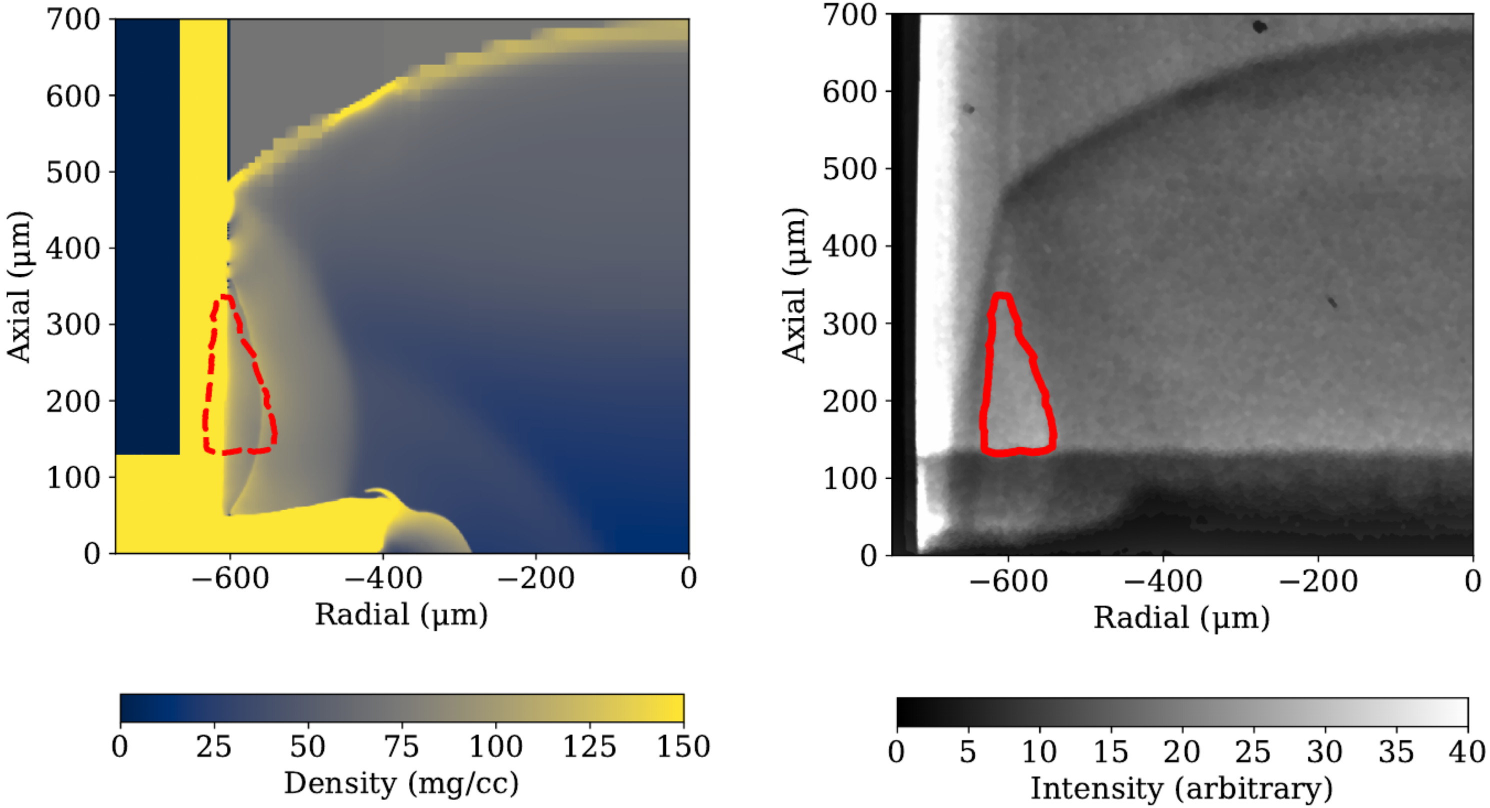




- Cassio simulations were generated by H. F. Robey.
- Inline CBET for indirect drive experiment
- No laser drive multiplier
- Flux limiter 0.05
- Can quantitatively interrogate fine scale differences

We are beginning to capture secondary features such a Be wall inflow to further constrain simulations

COAX 86456, t=4.3 ns

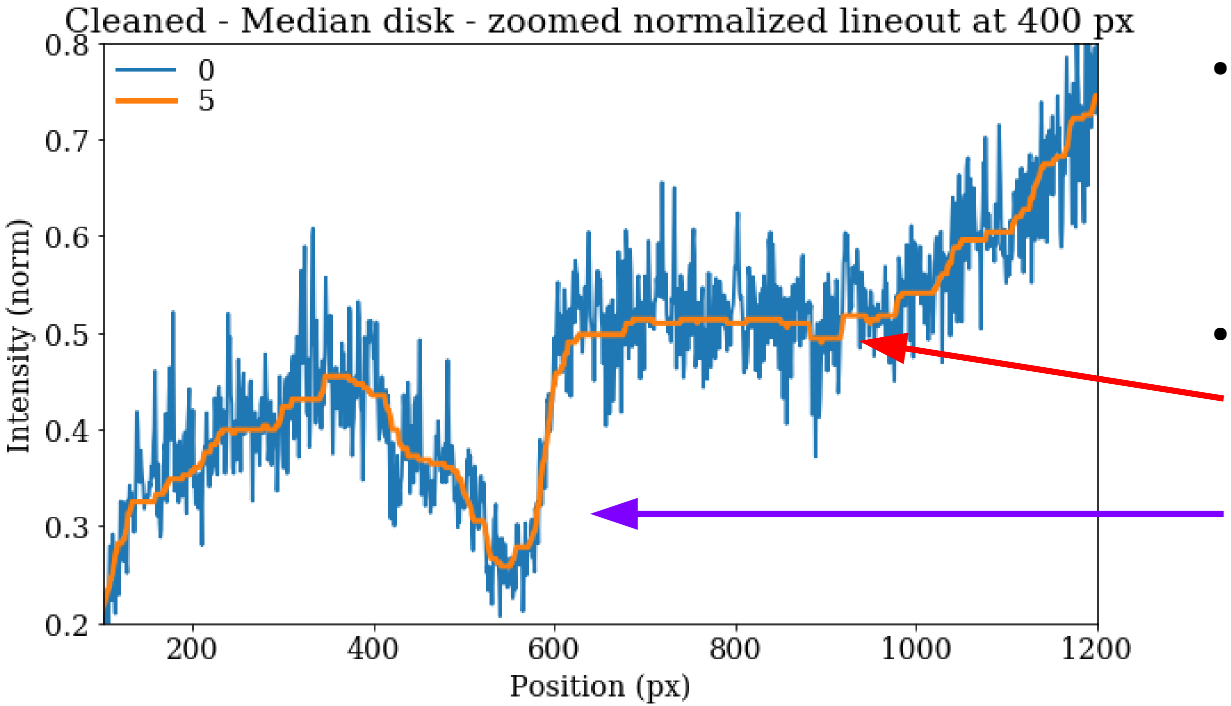


Conclusions

- Computer vision techniques can clean and enhance images as well as extract 2D feature contours to track shocks, bubble, and secondary features over time
- Extraction of these 2D contours enables detailed tracking of interactions (Mach stem in SBI) and symmetries in the system
- 2D contours also enable direct, quantitative comparisons with simulations, where 1D analyses may yield incorrect interpretations
- There is a wealth of secondary features to further explore!

Backup Slides

Intensity banding may occur for larger kernels – cleaning should be limited to smaller kernels



- Here, a disk kernel with 10 pixel radius was used for morphological filtering
- Banding is apparent in flat intensity regions, though gradient regions exhibit less banding

Comparison of contrast equalization techniques showed pseudo-flatfield works best for our data